Simulation of beam bunch length in the region of the fast beam chopper for different FETS MEBT lattices to allow for a performance comparison and to decide on the required RF amplifiers for start of purchasing.

1) Introduction

This document was prepared to compare the performance of the different proposed FETS MEBT lattices in one crucial aspect of the planned FETS Chopper experiments which is the bunch length of the beam inside the fast chopper. This aspect is crucial as the temporal separation of the bunches (together with the RF frequency) defines the time available for the chopper to switch from off to on.

"Perfect" beam chopping only can be demonstrated if no bunch will see any of the transient voltages in the fast chopper. At 324 MHz the available time is 3.0864 ns in total. As this time or below (range of times that could be seriously considered is in the range of to 2.40 ns to 1.543 ns equivalent to an bunch length of 80 to 180 degree of the RF) is already a challenge for high voltage electronics the particle dynamics design should be made such that sufficient time is allowed for the electronics.

In the first chapter the simulation parameters are described with most of the underlying data ether in the attachments or on the FETS WIKI. In the second chapter the results of various simulations are presented and in the third chapter the results will be summarized, discussed and conclusions for the MEBT in respect to the power requirement of the (first) amplifier drawn.

1) Simulation Parameters

From the available documentation (see Appendix A-D) the following parameters for the position (and length) of the first two cavities and the fast beam chopper. The numbers are presented in the following table:

MEBT_12_RBCx4_SCHEME_1

Cavity 1	492 mm	200 mm
Cavity 2	1520 mm	200 mm
Chopper	1125 mm	450 (470) mm

MEBT_12_RBCx4_SCHEME_2

Cavity 1	492 mm	200 mm
Cavity 2	1520 mm	200 mm
Chopper	1125 mm	450 (470) mm

MEBT_12_RBCx4_600_LONG_CHOPPER

Cavity 1	512 mm	200 mm
Cavity 2	1760 mm	200 mm
Chopper	1294 mm	600 (630) mm

MEBT_12_RBCx3_604.5_LONG_CHOPPER

Cavity 1	735 mm	200 mm
Cavity 2	2745 mm	200 mm
Chopper	1270 mm	604.5 (635) mm

The following parameters for the RF cavity voltages have been derived from the RF power table of the first two cavities and the fast beam chopper. The numbers are presented in the following table:

21st August:

70900 / 88635

30th May:

original 4 cavity lattice:

126.5	7.485	9.375	10.31	15
121.8	6.93	8.66	9.52	10

alternative 4 cavity lattice:

76	2.71	3.38	3.72	5
73	2.49	3.11	3.42	5

3 cavity lattice

1	5.45	6.8125	7.493	10
2	2.15	2.68	2.948	5

(kV)	GPTscale	voltage	power	plus 25%	plus 10%
155.15	0.8153	126.5	7.485	9.375	10.31
155.15	0.78506	121.8	6.93	8.66	9.52
155.15	0.4785	74.3	2.58	3.225	3.54
155.15	0.43031	66.8	2.08	2.6	2.86

Amplitudes chosen for the two cavities considered in this simulation :

4 cavity lattice:

test1 : SCALE1=0.4567; SCALE2=0.4567;

test2 : SCALE1=0.66; SCALE2=0.66;

test3 : SCALE1=0.815; SCALE2=0.66;

3 cavity lattice:

test1 : SCALE1=0.66; SCALE2=0.66;

test2 : SCALE1=0.66; SCALE2=0.66;

test3 : SCALE1=0.57; SCALE2=0.66;

The phasing of the cavities has been investigated and the following values have been used:

4 cavity lattice:

test1 : PHASE1=1.542; PHASE2=2.395;

test2 : PHASE1=1.542; PHASE2=2.395;

test3 : PHASE1=1.542; PHASE2=2.395;

3 cavity lattice:

test1 : PHASE1=-1.012; PHASE2=-1.19;

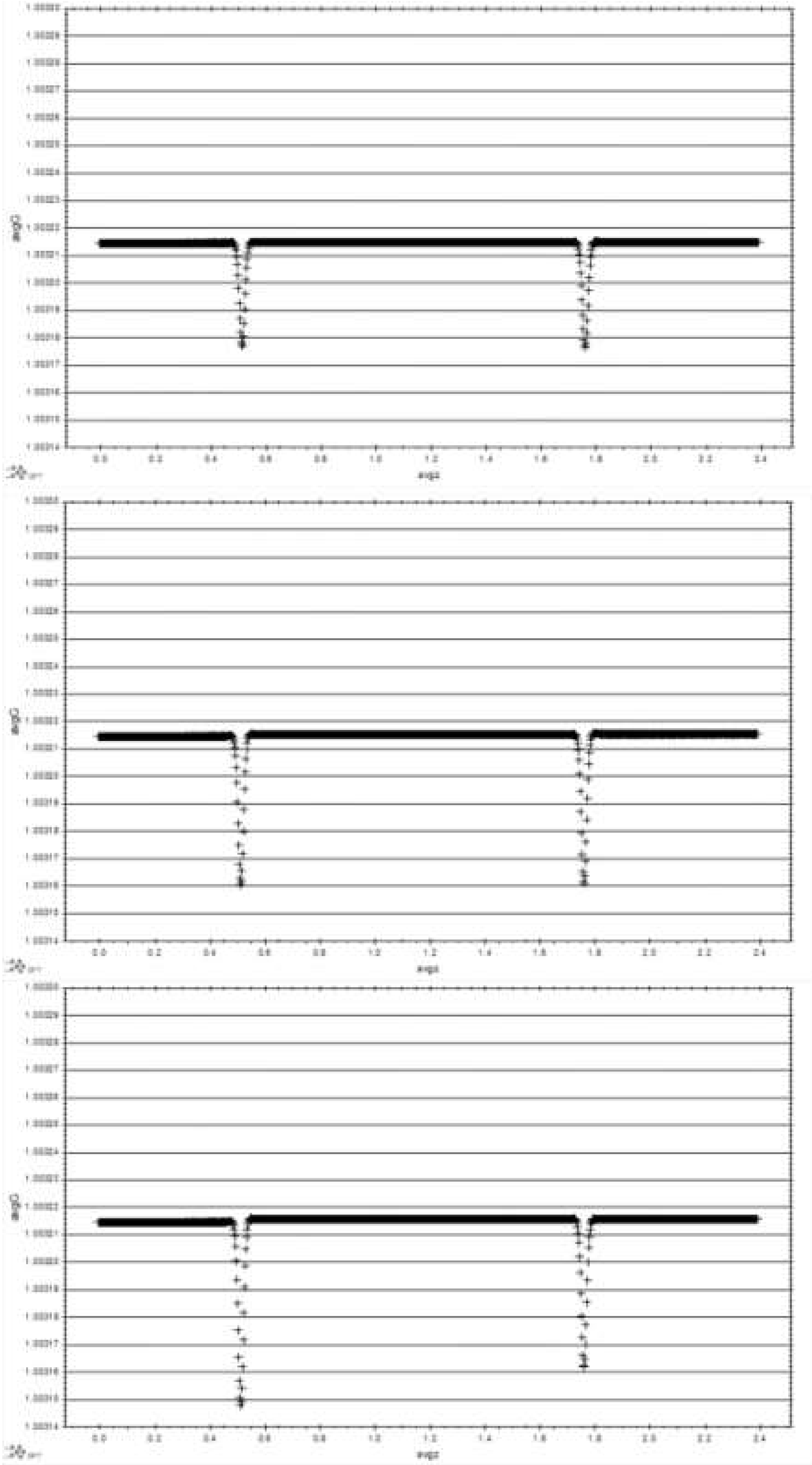
test2 : PHASE1=1.465; PHASE2=0.49;

test3 : PHASE1=1.465; PHASE2=0.49;

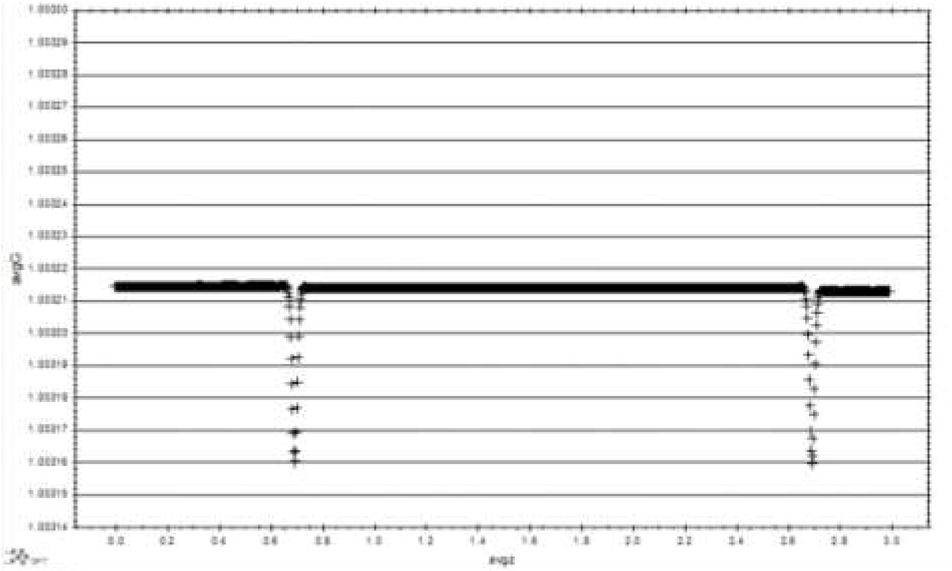
2) Simulation results

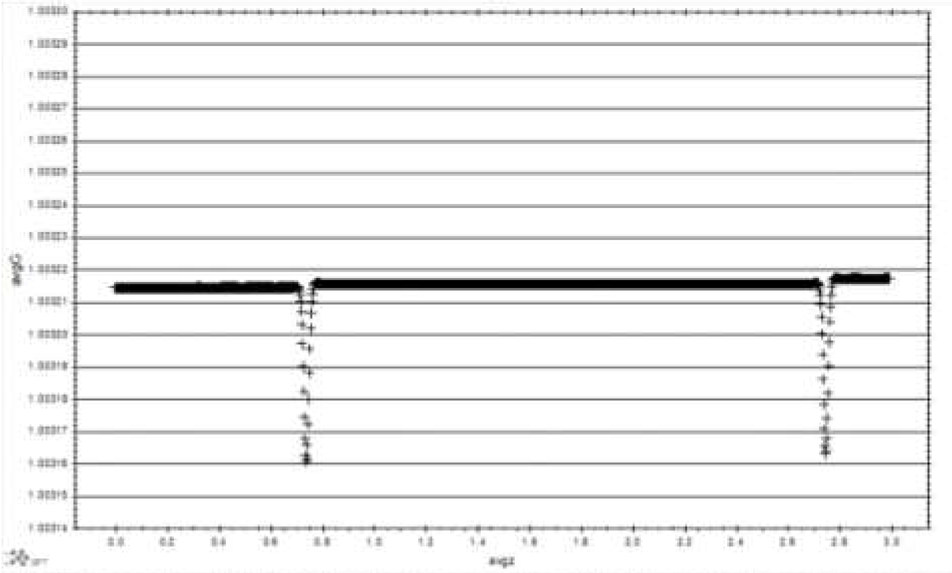
Test of phase setting of cavity to produce beam bunching and a constant mean energy....y scal is equivalent to the initial energy spread from the RFQ

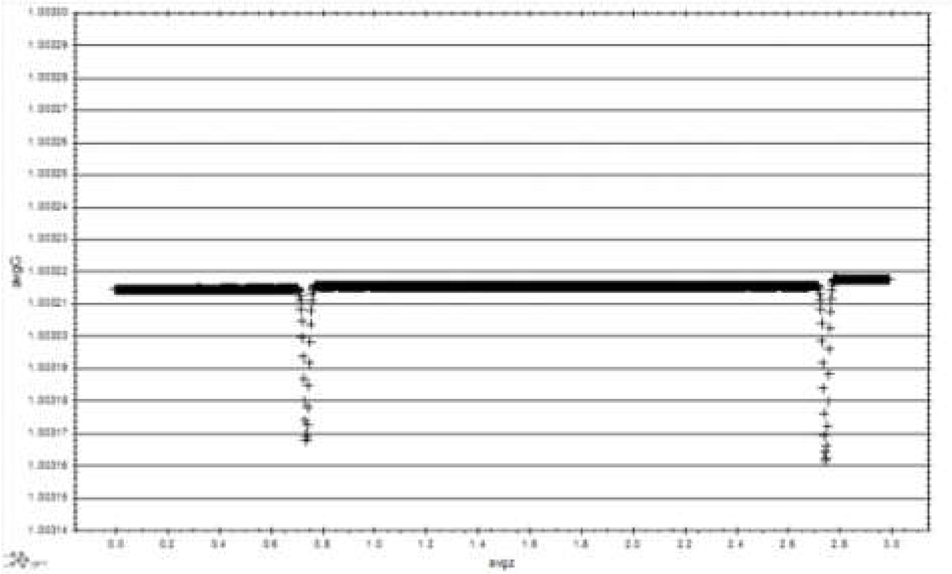
4cavitytest1-3



3cavitytest1-3

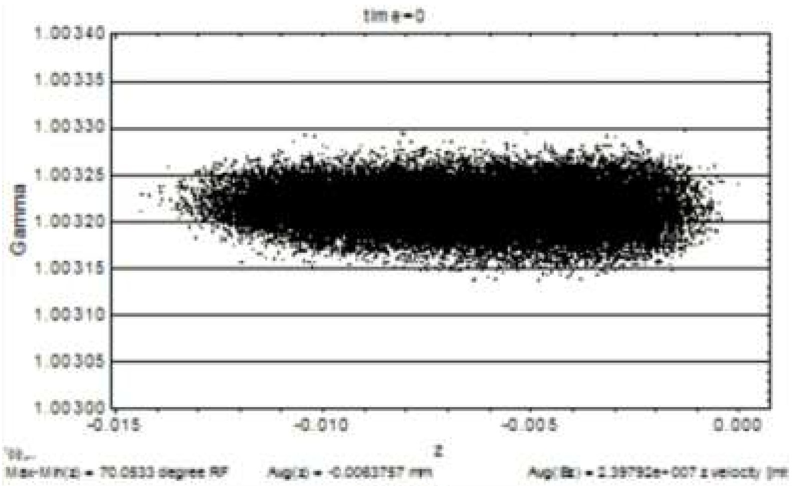


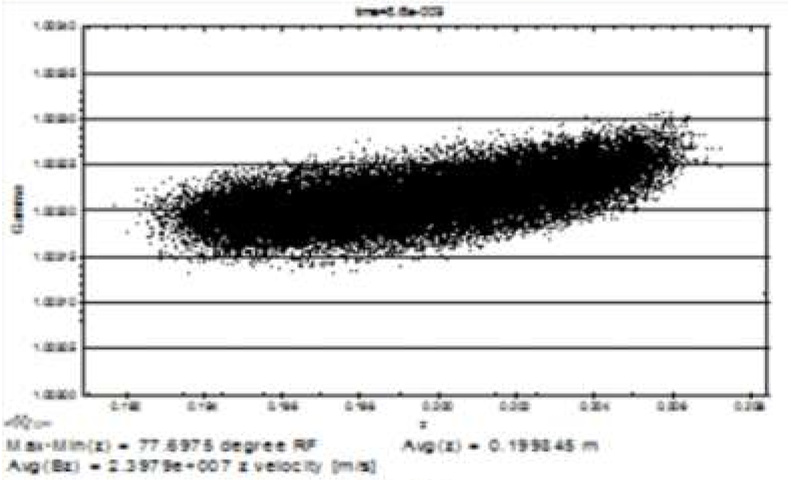


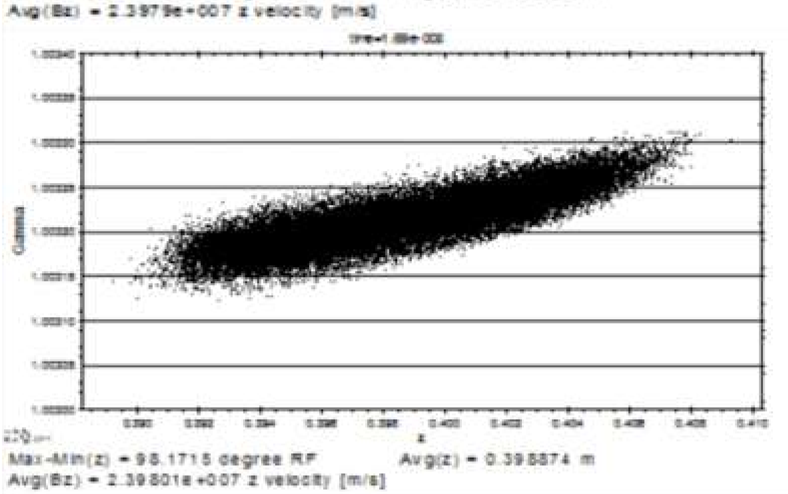


Investigation of bunch length for various positions along the MEBT for the 6 different cases simulated.

the fist 40 cm are common for all simulations:

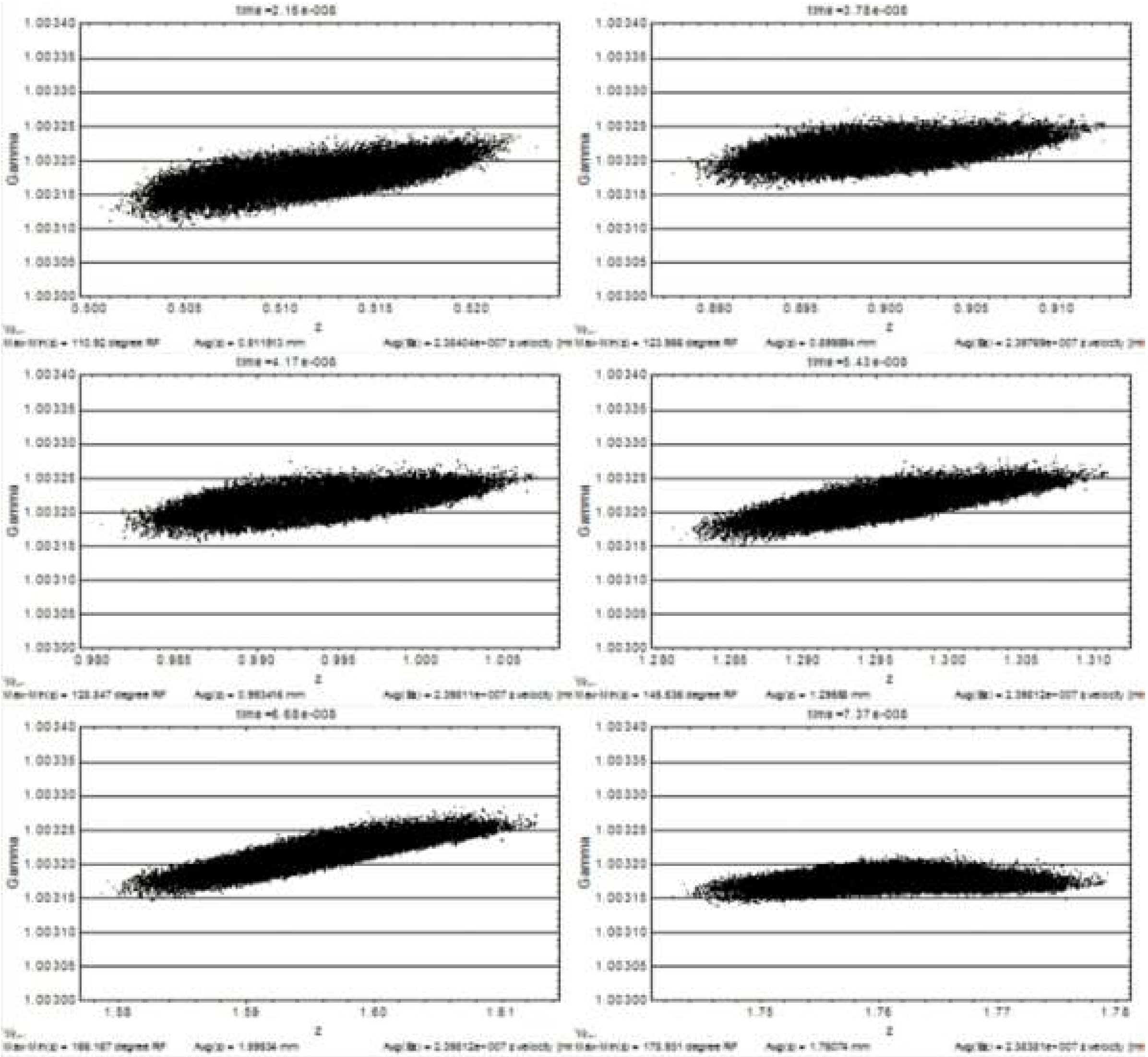




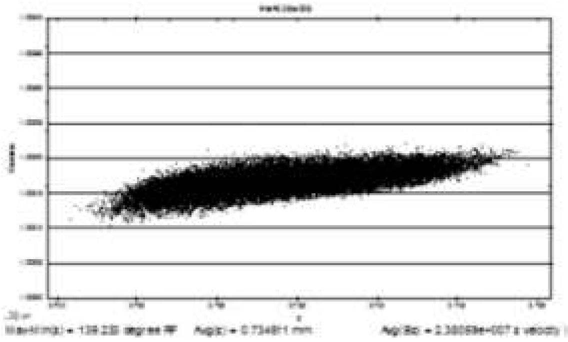


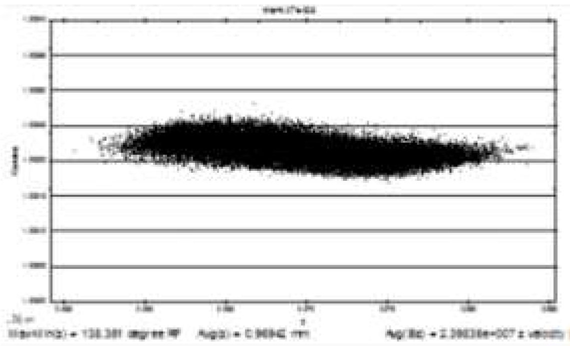
Following are only the detailed results for the 4 cavities case 1, and the 3 cavities case 3 which were the ones for decission. The other results are summarized in the table and plot following.

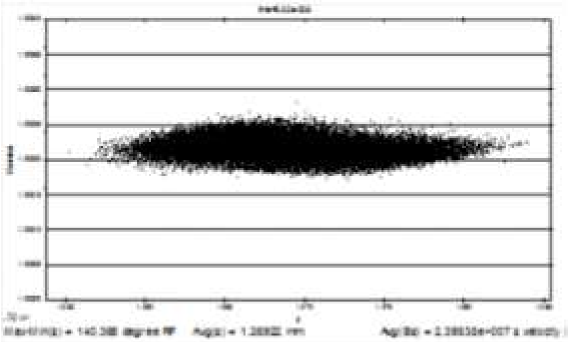
4ctest1

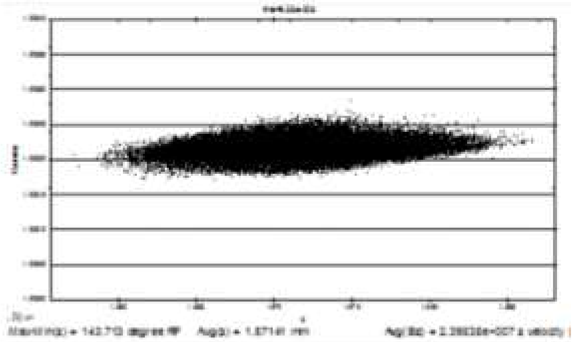


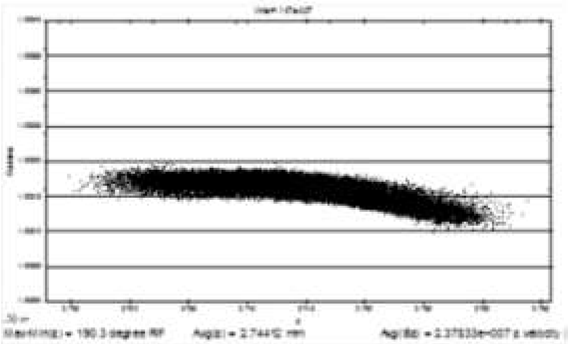
3ctest3





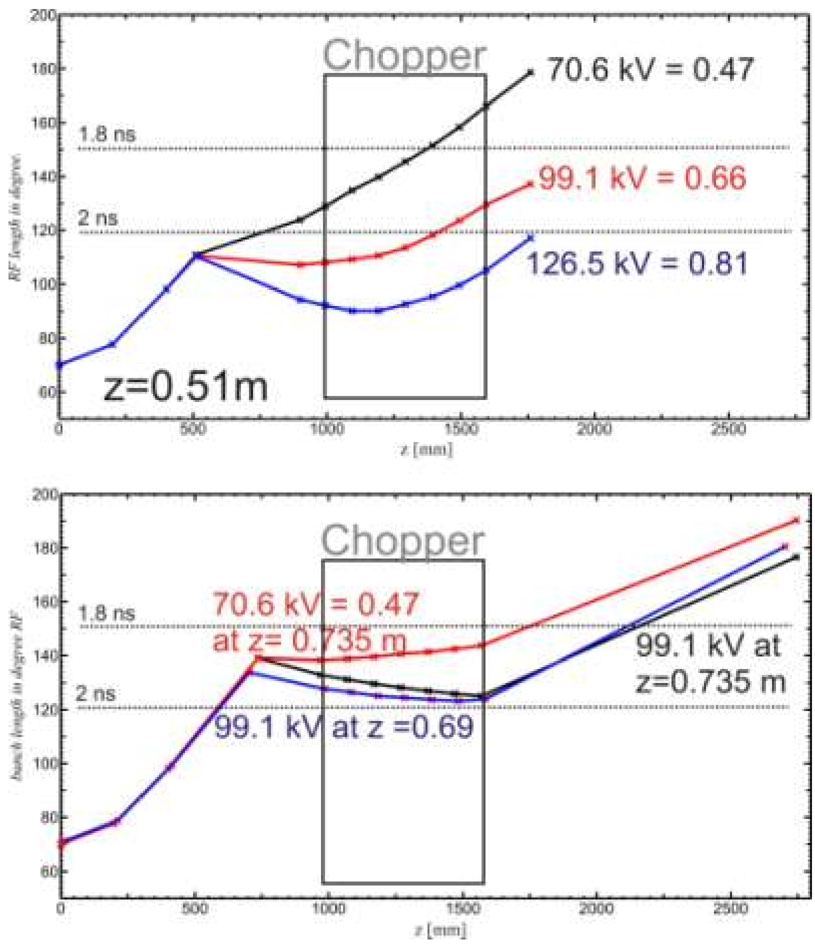






Comparison table and plot :

C4test1		C4test2		C4test3		C3test1		C3test2		C3test3	
Z (mm)	RF (degree)	Z (mm)	RF (degree)	Z (mm)	RF (degree)	Z (mm)	RF (degree)	Z (mm)	RF (degree)	Z (mm)	RF (degree)
0	70.05	0	70.05	0	70.05	0	70.05	0	70.05	0	70.05
200	77.69	200	77.69	200	77.69	200	77.69	200	77.69	200	77.69
400	98.17	400	98.17	400	98.17	400	98.17	400	98.17	400	98.17
512	110.92	512	110.54	512	110.26	690	132.78	735	139.14	735	139.23
900	123.95	900	107.12	900	94.33	970	126.68	970	132.99	970	138.35
994	128.84	994	108.02	994	92.21	1070	125.41	1070	131.24	1070	138.88
1094	134.84	1094	109.18	1094	90.17	1170	124.03	1170	129.65	1170	139.56
1194	139.81	1194	110.62	1194	90.19	1270	123.38	1270	128.25	1270	140.66
1294	145.53	1294	113.51	1294	92.64	1370	122.66	1370	127	1370	141.33
1394	151.54	1394	118.21	1394	95.46	1470	122.15	1470	125.93	1470	142.44
1494	158.34	1494	123.59	1494	99.58	1570	122.83	1570	125.13	1570	143.71
1594	166.16	1594	129.5	1594	105.09	2690	179.45	2745	176.63	2745	190.3
1760	178.5	1760	137.23	1760	117.09						



Upper plot shows 4 cavity case, lower plot shows 3 cavity case.

3) Discussion and conclusions

.....very briefly and with my own view....

1) In all cases we seem to need RF power on the level of 0.6 - 0.7 (GPT, ~ 99.1 kV, ~5.5 kW with safety margin at 0.66)

2) For the 600 mm chopper positioned shortly before 1 m and ~ 0.66 amplitude scaling the best position of the buncher would be at ~ 0.6 m - but this has to fit the transversal optics as well !

3) The discussed larger bore shorter cavity would be very helpful in every aspect and should be adopted.

4) The larger bore radius cavity should also increase safety margin for the chopped beam crossing it in 4 cavity lattice. If checked this should be sufficient.

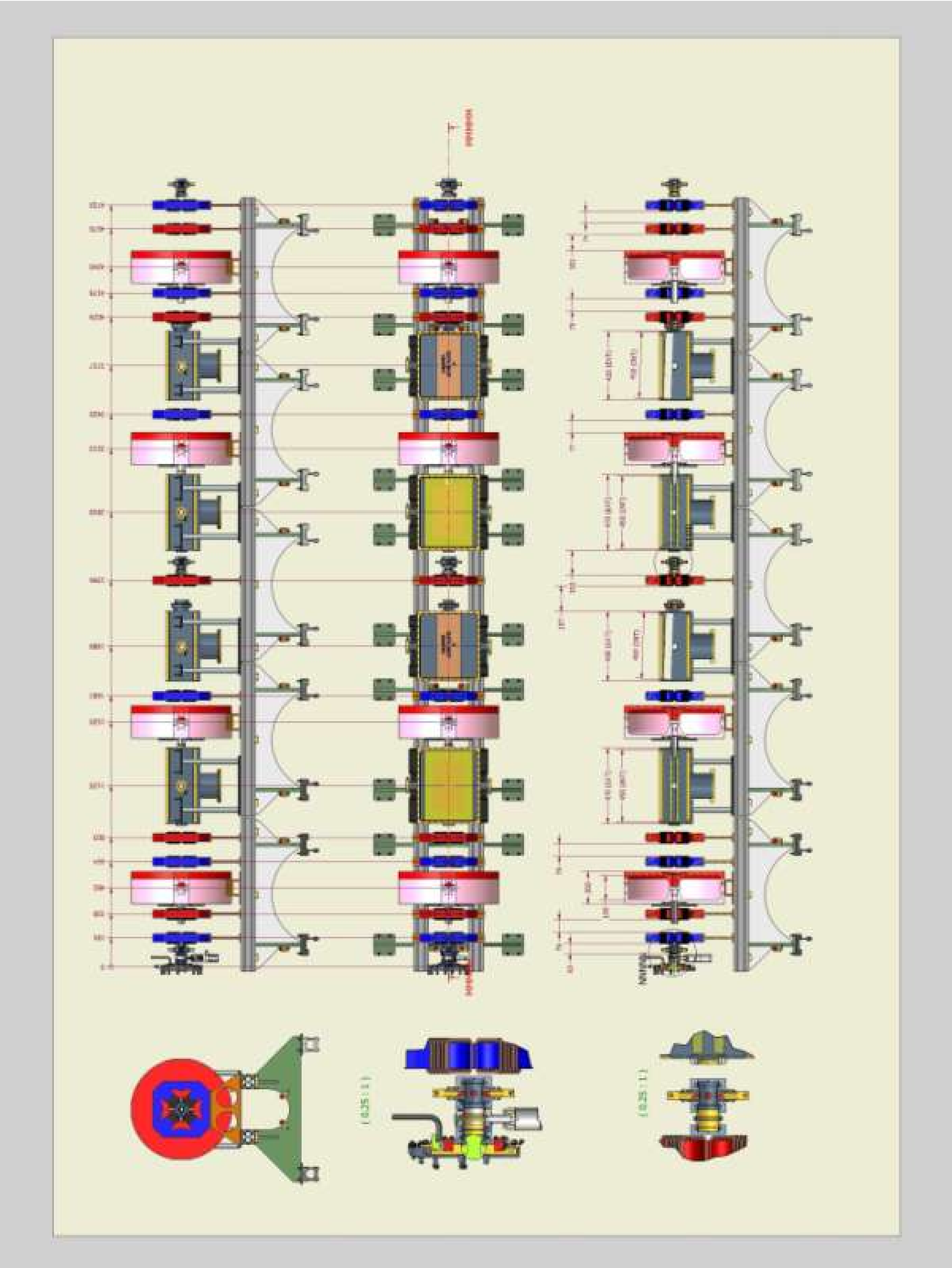
5) If for the 4 cavity lattice a solution can be found to allow for sufficient space (110 mm) for two BPMs (a triplet instead of two doublets could be used together with the shorter cavity) which is competitive I see no further reason not to agree and freeze the lattice and start with the mechanical design.

6) I would also adopt the 80 mm quadrupoles in this process.

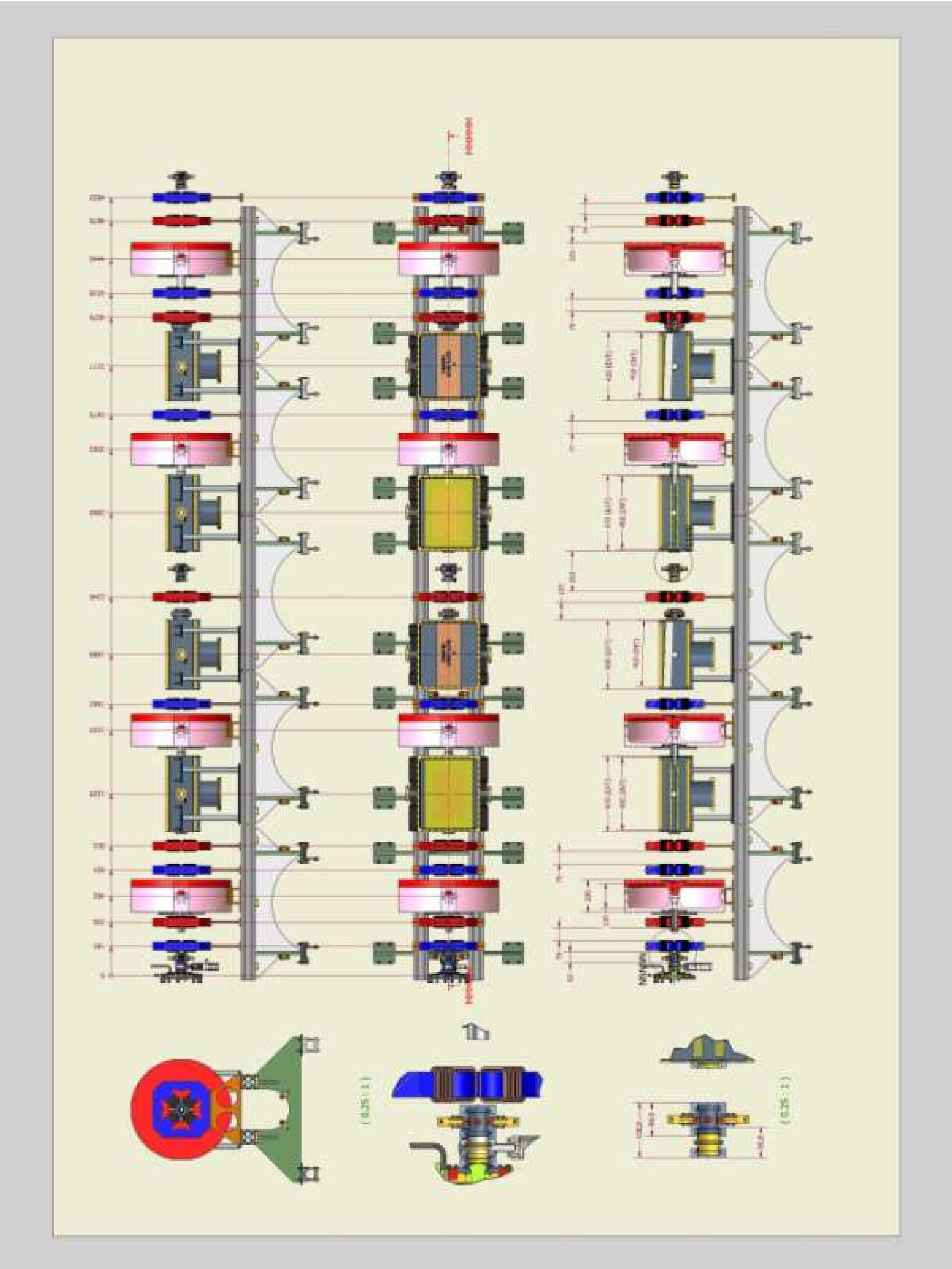
7) For the decision we would need the full results of one consistent run with all changes incorporated.

8) Under those assumptions, I would suggest to built the cavities in the following way : 3 cavities conventional + RF amplifiers (I assume a 7 kW unit and a 4+3 kW unit is sufficient but should check) - the fourth cavity can be seen as spare (or included if one wishes) but we should also consider the chance to built it as a direct drive cavity test (Alan do you think SIEMENS would be interested ?)

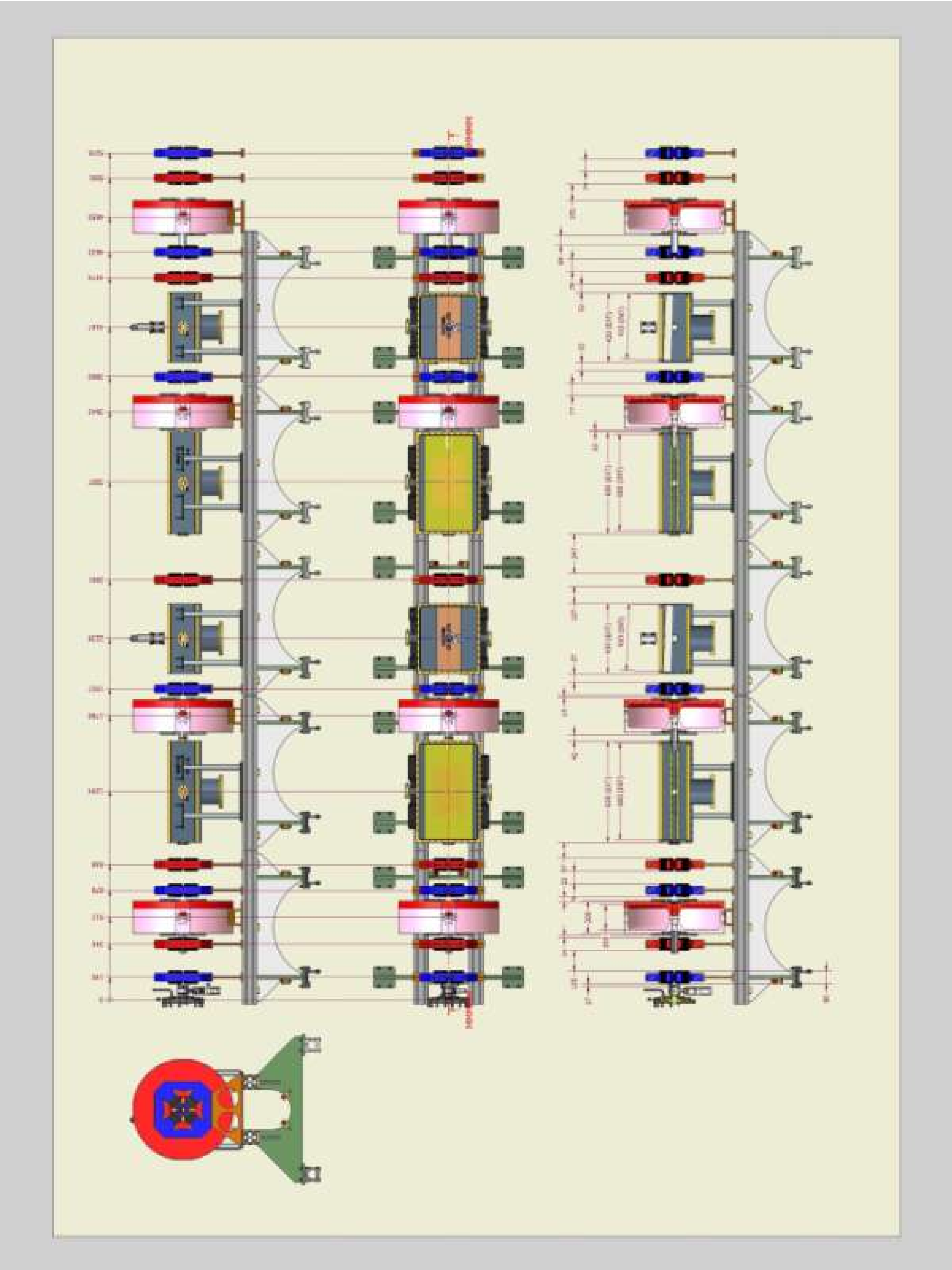
Appendix A 4 cavities lattice scheme 1



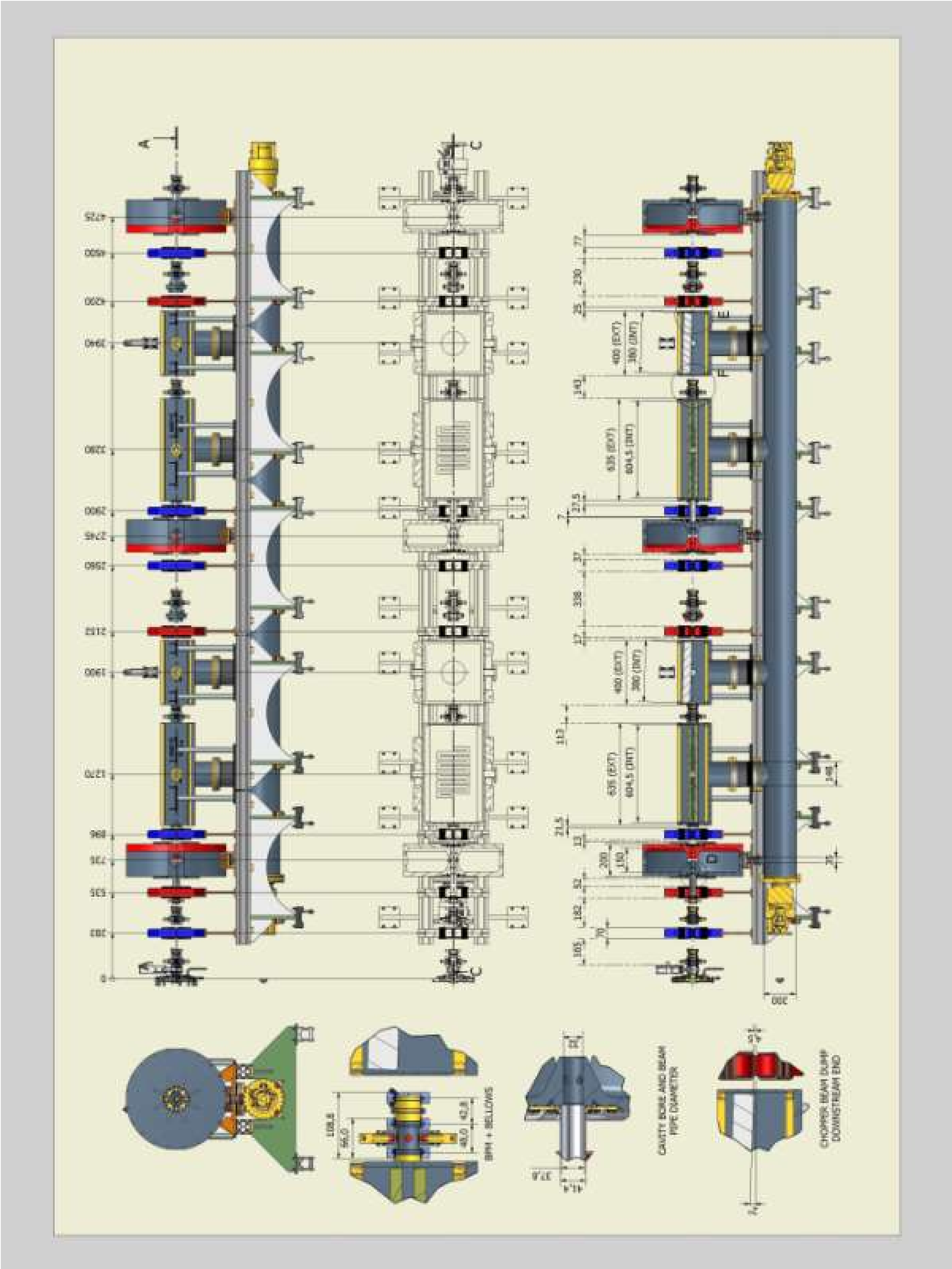
Appendix B 4 cavities lattice scheme 2



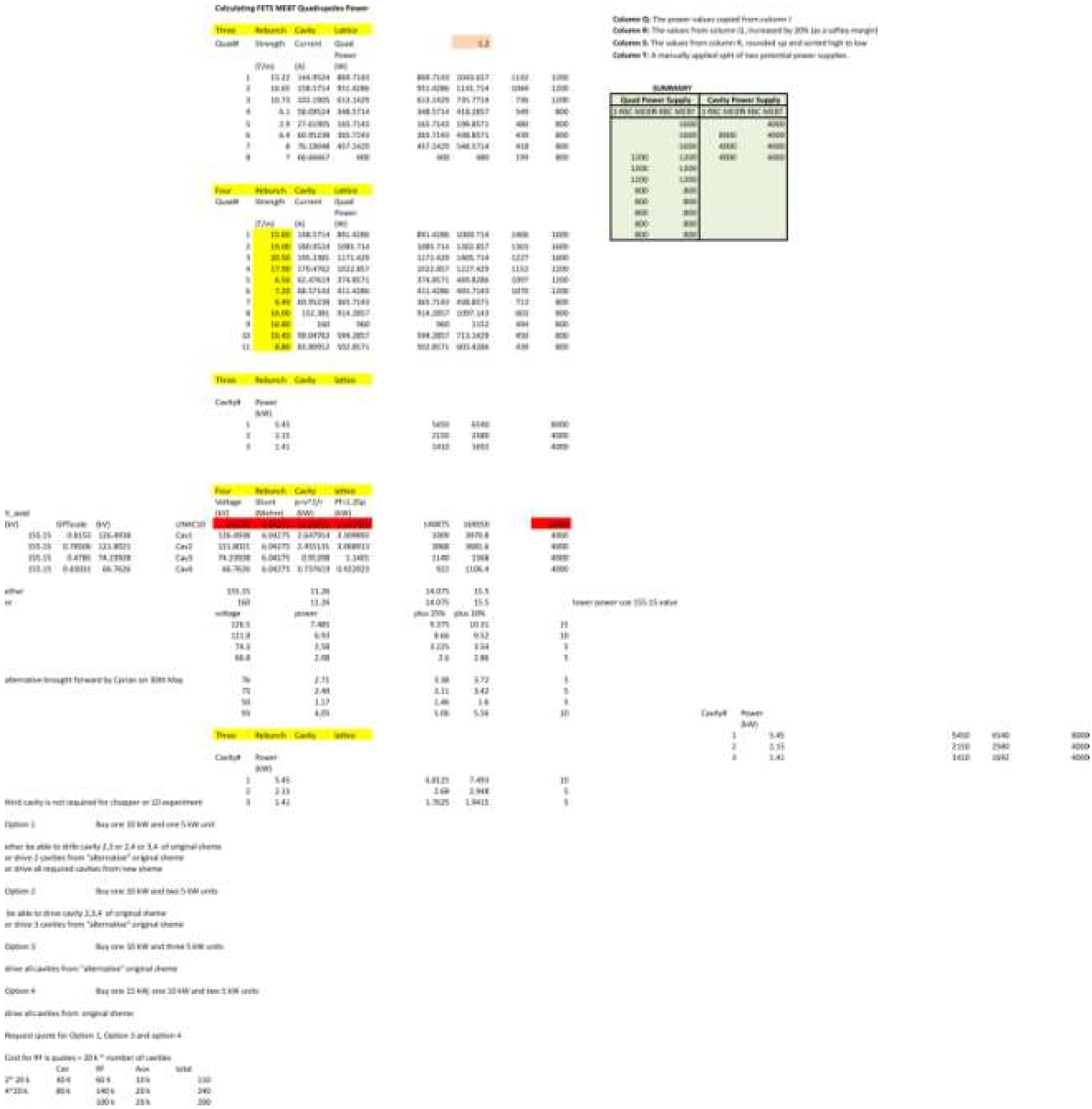
Appendix C 4 cavities lattice - last version - long chopper



Appendix D - 3 cavity lattice last version



Appendix E - Calculations for MEBT quads and RF power requirements (spreadsheet)



Calculating FETS MEBT Quadrupoles Power

SUMMARY

Quad Power Supply	Cavity Power Supply

Appendix F - Comparison document (21st Aug 2013 / 23rd Aug 2013)

	MEBT_A_80_mm (38 mm aperture)	MEBT Morteza
Input	RFQ Dist	RFQ Dist
No. of Quads	9	6*
Quadrupole length (mm)	80	70
Highest Quad. Grad (T/m)	17.5	16.59
No. of Cavities	3	2
Total Length (mm)	4750	4150
Highest Cavity Voltage (V)	70900	88635
Cumulated Beam Loss (%)	0.71	2.7
Cumulated Beam Loss (W)	142	
Emittance growth X, Y, Z (%)	25.0, 16.3, 8.8	31, 0.34, -1.13
Fast Ch. Electr. Length (mm)	600	604.5
Fast Ch. Effective Electr. Voltage (V)	+/-1100	+/-1080
Fast Ch. Beam Extinction (%)	99.69	99.79
Fast Ch. Beam Dump Peak Power Dens. (W/mm2)	216	100 < 200
Slow Ch. Electrode Length (mm)	600	604.5
Slow Ch. Effective Electrode Voltage (V)	+/-1275	+/-1275
Slow Ch. Beam Extinction (%)	99.93	99.99
Slow Ch. Beam Dump Peak Power Dens. (W/mm2)	216	100 < 200

Appendix G - GPT input files

1) "4cavitylongtest1.in"

```
# Simulation parameters

Qtot=-1.85185e-10;    # Set Total bunch charge (( 1/324e6) x 0.06 A beam current

m=mp+2*me;

q=qe;

setfile("beam", "GhostinZ_100k.gdf"); #about 100,000 particles

setshuffle("beam");

settotalcharge("beam", Qtot);

spacecharge3Dmesh("MeshNtotal",38,38,80,"SolverAcc",0.01);

# Lattice Set-up

screen("wcs","I",0);

rectcoil("wcs","z",0.2,0.05,0.1,0.3,470000);

SCALE1=0.4567;

PHASE1=1.542;

frequency1=324e6;

k1=0.0;

map25D_TM("wcs","z",0.512,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE1,k1,PHAS
E1, 2*pi*frequency1);

rmax ("wcs","z",0.512, 0.015,0.2);

rectcoil("wcs","z",0.85,0.05,0.1,0.1,310000);

SCALE2=0.4567;

PHASE2=2.395;

frequency2=324e6;

k2=0.0;

map25D_TM("wcs","z",1.760,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE2,k2,PHAS
E2, 2*pi*frequency2);

rmax ("wcs","z",1.760, 0.015,0.2);

#Simulation output control

tout(0, 1.0e-7, 1e-10);             # using new(fast) gdftrans file:
```

dtmax = 5E-11;

2) "4cavitylongtest2.in"

Lattice Set-up

screen("wcs","I",0);

rectcoil("wcs","z",0.2,0.05,0.1,0.3,470000);

SCALE1=0.66;

PHASE1=1.542;

frequency1=324e6;

k1=0.0;

map25D_TM("wcs","z",0.512,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE1,k1,PHASE1, 2*pi*frequency1);

rmax ("wcs","z",0.512, 0.015,0.2);

rectcoil("wcs","z",0.85,0.05,0.1,0.1,310000);

SCALE2=0.66;

PHASE2=2.395;

frequency2=324e6;

k2=0.0;

map25D_TM("wcs","z",1.760,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE2,k2,PHASE2, 2*pi*frequency2);

rmax ("wcs","z",1.760, 0.015,0.2);

3) "4cavitylongtest3.in"

Lattice Set-up

screen("wcs","I",0);

rectcoil("wcs","z",0.2,0.05,0.1,0.3,470000);

SCALE1=0.815;

PHASE1=1.542;

frequency1=324e6;

k1=0.0;

map25D_TM("wcs","z",0.512,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE1,k1,PHASE1, 2*pi*frequency1);

rmax ("wcs","z",0.512, 0.015,0.2);

rectcoil("wcs","z",0.85,0.05,0.1,0.1,310000);

SCALE2=0.66;

PHASE2=2.395;

frequency2=324e6;

k2=0.0;

map25D_TM("wcs","z",1.760,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE2,k2,PHASE2, 2*pi*frequency2);

rmax ("wcs","z",1.760, 0.015,0.2);

4) "3cavitylongtest1.in"

Lattice Set-up

screen("wcs","I",0);

rectcoil("wcs","z",0.2,0.05,0.1,0.3,470000);

SCALE1=0.66; # was 0.65

PHASE1=-1.012; #0.522;

frequency1=324e6;

k1=0.0;

map25D_TM("wcs","z",0.690,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE1,k1,PHASE1, 2*pi*frequency1);

rmax ("wcs","z",0.690, 0.015,0.2);

rectcoil("wcs","z",0.85,0.05,0.1,0.1,310000);

SCALE2=0.66;

PHASE2=-1.19;

frequency2=324e6;

k2=0.0;

map25D_TM("wcs","z",2.690,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE2,k2,PHASE2, 2*pi*frequency2);

rmax ("wcs","z",2.690, 0.015,0.2);

5) "3cavitylongtest2.in"

Lattice Set-up

screen("wcs","I",0);

rectcoil("wcs","z",0.2,0.05,0.1,0.3,470000);

SCALE1=0.66;

PHASE1=1.465;

frequency1=324e6;

k1=0.0;

map25D_TM("wcs","z",0.735,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE1,k1,PHASE1, 2*pi*frequency1);

rmax ("wcs","z",0.735, 0.015,0.2);

rectcoil("wcs","z",0.85,0.05,0.1,0.1,310000);

SCALE2=0.66; # C2

PHASE2=0.49; #1.339; # + 0.8156;

frequency2=324e6;

k2=0.0;

map25D_TM("wcs","z",2.745,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE2,k2,PHASE2, 2*pi*frequency2);

rmax ("wcs","z",2.745, 0.015,0.2);

6) "3cavitylongtest3.in"

Lattice Set-up

screen("wcs","I",0);

rectcoil("wcs","z",0.2,0.05,0.1,0.3,470000);

SCALE1=0.57;

PHASE1=1.465;

frequency1=324e6;

k1=0.0;

map25D_TM("wcs","z",0.735,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE1,k1,PHASE1, 2*pi*frequency1);

rmax ("wcs","z",0.735, 0.015,0.2);

rectcoil("wcs","z",0.85,0.05,0.1,0.1,310000);

SCALE2=0.66; # C2

PHASE2=0.49; #1.339; # + 0.8156;

```
frequency2=324e6;

k2=0.0;

map25D_TM("wcs","z",2.745,"mebt_sf_map.gdf","R","Z","Er","Ez","H",SCALE2,k2,PHAS
E2, 2*pi*frequency2);

rmax ("wcs","z",2.745, 0.015,0.2);
```